Session NP 1
1.1 The Chemical Context of Life

Book Chapters: 2, 3, 4 Campbell[7,9]

Adapted from:

PowerPoint® Lecture Presentations for

Biology

8th and 9th Editions

Neil Campbell and Jane Reece

Graduate in Biology, First Year, Biology Classses
University of Valencia

Adapted by:
Joaquín Baixeras
Emilia Matallana
Juli Peretó
Felisa Puche
Francisco Ruiz
Carles Soler

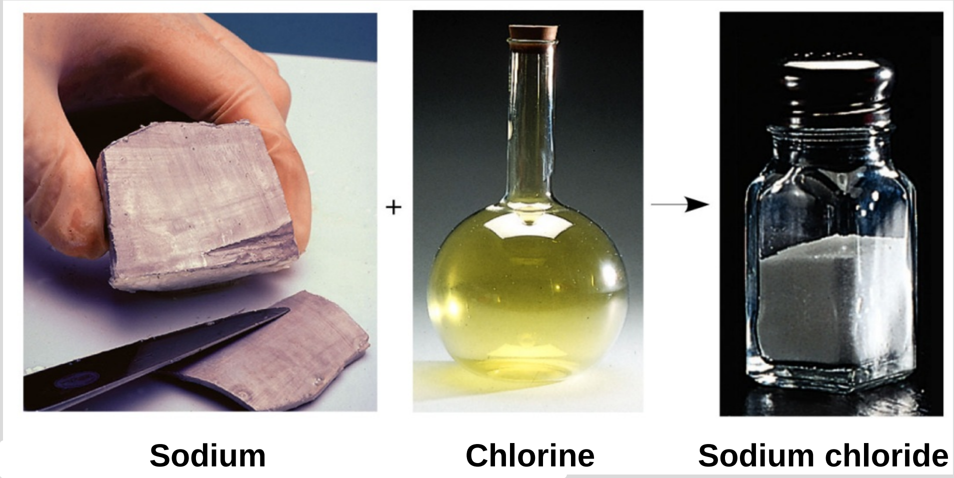
Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

Overview: Chemical Foundations of Biology

- Biology is a multidisciplinary science
- Living organisms are subject to basic laws of physics and chemistry
- One example is the bombardier beetle, which uses chemistry to defend itself

Concept 1.1.1: Matter consists of chemical elements in pure form and in combinations called compounds

- Organisms are composed of matter
- Matter is anything that takes up space and has mass and it is made up of elements



- An element is a substance that cannot be broken down to other substances by chemical reactions
- A compound is a substance consisting of two or more elements in a fixed ratio

Essential Elements of Life

- About 25 of the 92 elements are essential to life
- C, H, O, and N make up 96% of living matter. Most of the remaining 4% consists of Ca, P, K, and S
- Trace elements are those required by an organism in minute quantities

Nitrogen deficiency **Iodine deficiency**

(a) (b)

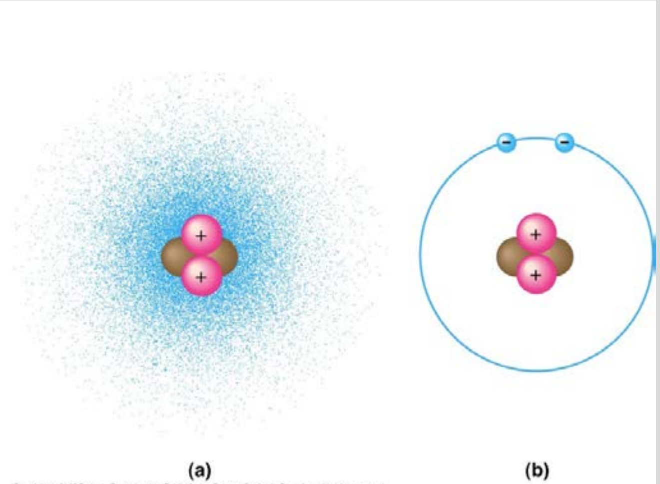
Table 2.1 Naturally Occurring Elements in the Human Body

Symbol	Element	Atomic Number (See p. 34)	Percentage of Human Body Weight
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1

Trace elements (less than 0.01%): boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

Concept 1.1.1: An element’s properties depend on the structure of its atoms

- Each element consists of unique atoms
- An atom is the smallest unit of matter that still retains the properties of an element

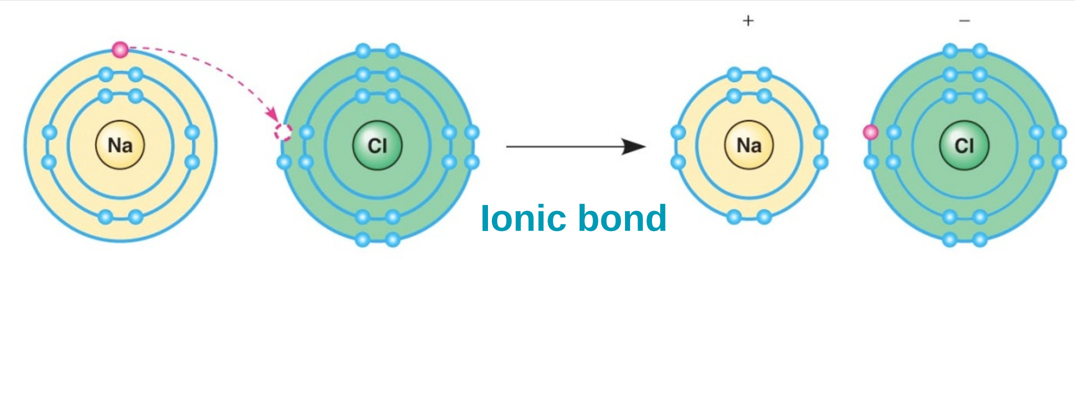


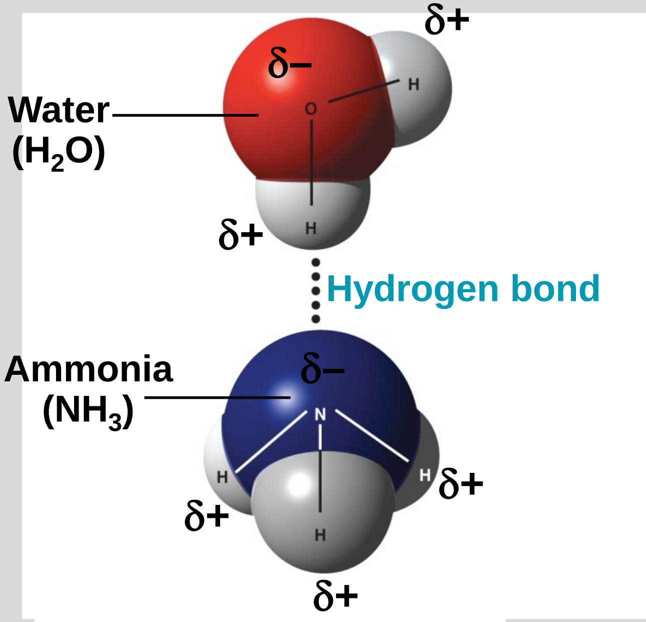
Concept 1.1.3: The formation and function of molecules depend on chemical bonding between atoms

- A covalent bond is the sharing of a pair of valence electrons by two atoms
- In a covalent bond, the shared electrons count as part of each atom’s valence shell

Weak Chemical Bonds

- Most of the strongest bonds in organisms are covalent bonds that form a cell's molecules
- Weak chemical bonds, such as ionic bonds and hydrogen bonds, are also important





Weak chemical bonds reinforce shapes of large molecules and help molecules adhere to each other

Van der Waals Interactions

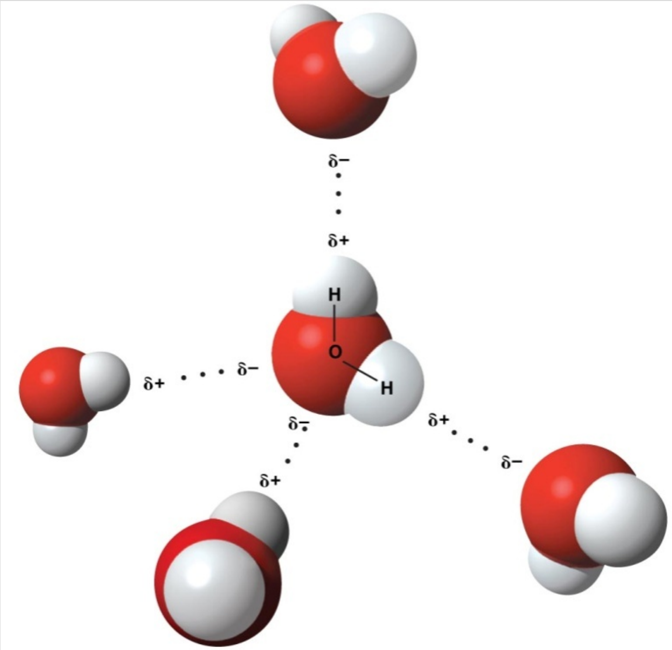
- Molecules or atoms that are very close together can be attracted by fleeting charge differences
- These weak attractions are called van der Waals interactions
- Collectively, such interactions can be strong, as between molecules of a gecko's toe hairs and a wall surface

The Molecule That Supports All of Life

- Water is the biological medium on Earth
- All living organisms require water more than any other substance
- Most cells are surrounded by water, and cells themselves are about 70-95% water
- The abundance of water is the main reason the Earth is habitable

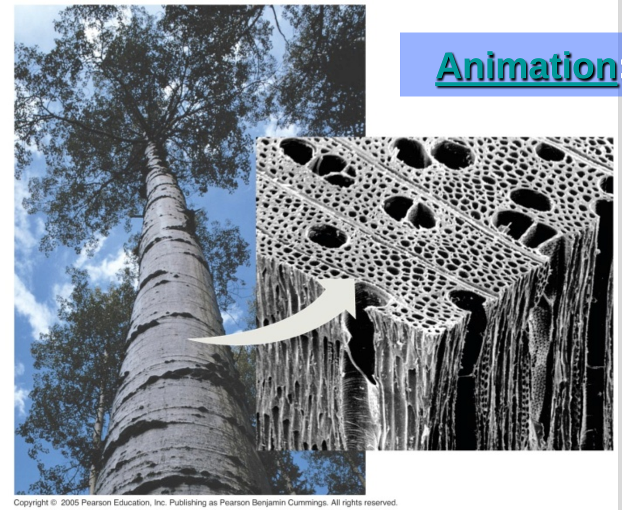
Concept 1.1.4: The polarity of water molecules results in hydrogen bonding

- The water molecule is a polar molecule: The opposite ends have opposite charges
- Polarity allows water molecules to form hydrogen bonds with each other



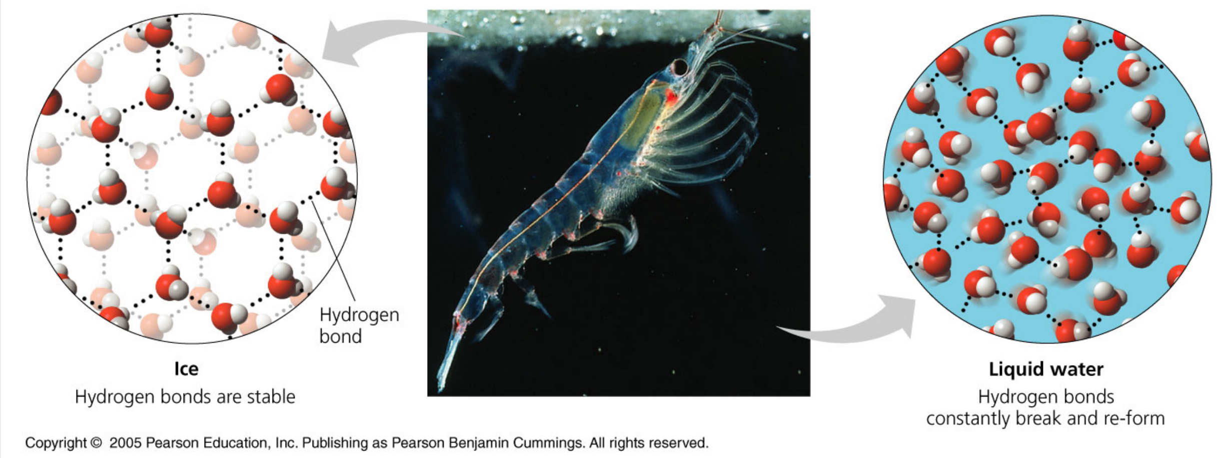
Animation: Water Structure

Concept 1.1.5: Four emergent properties of water contribute to Earth's fitness for life



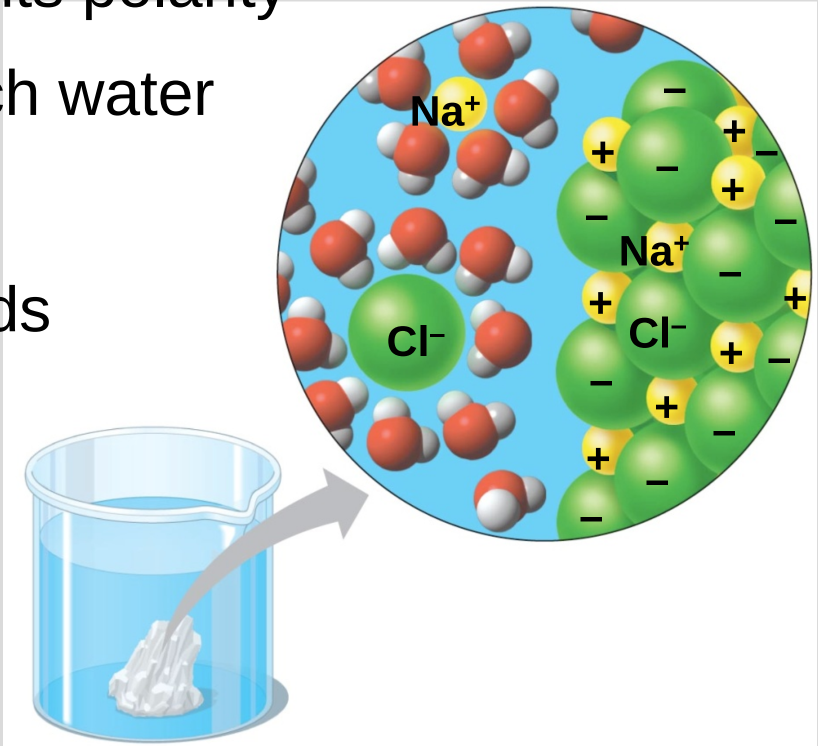
Animation: Water Transport

Cohesive behavior
Ability to moderate temperature
Expansion upon freezing
Versatility as a solvent



The Solvent of Life

- A solution is a liquid that is a homogeneous mixture of substances
- A solvent is the dissolving agent of a solution
- The solute is the substance that is dissolved
- Water is a versatile solvent due to its polarity
- An aqueous solution is one in which water is the solvent
- Water readily forms hydrogen bonds

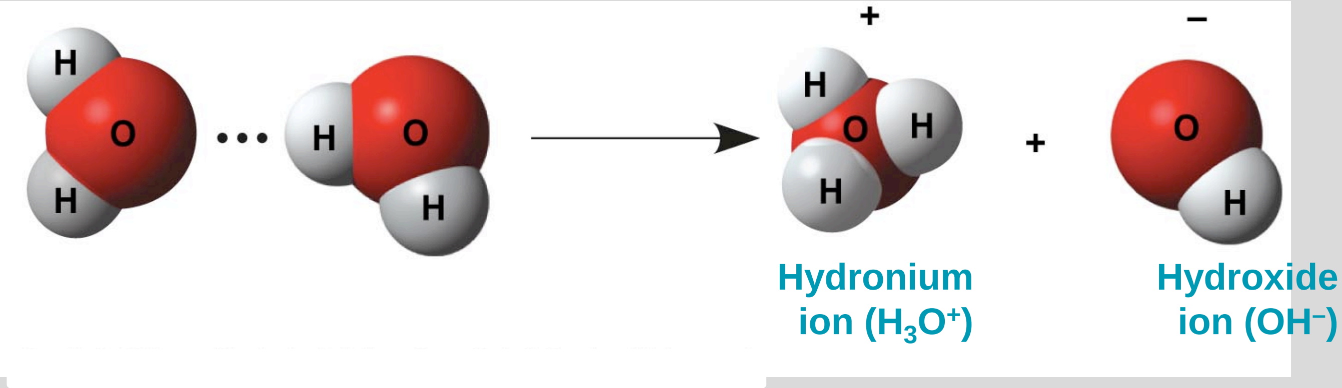


Hydrophilic and Hydrophobic Substances

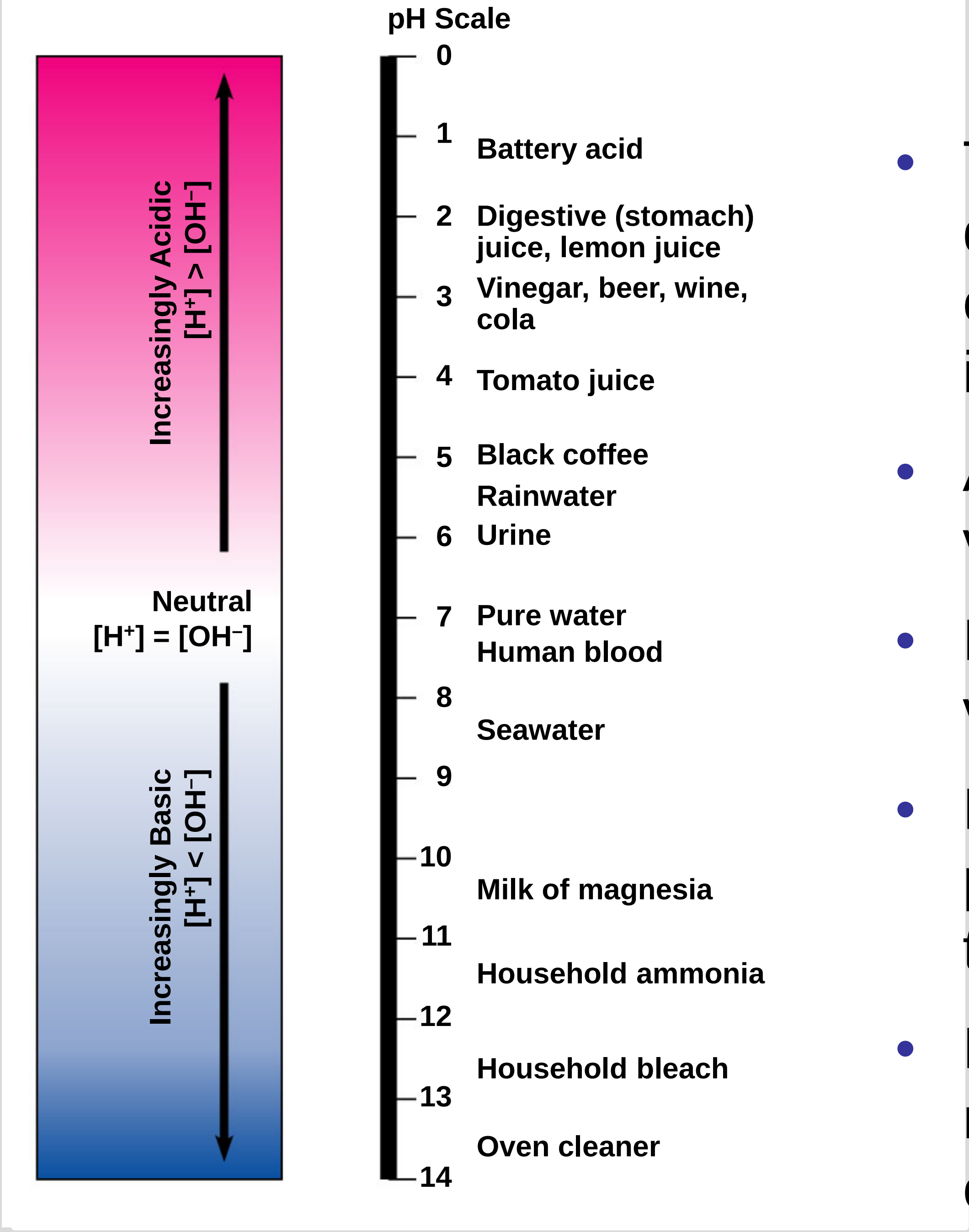
- A hydrophilic substance is one that has an affinity for water
- A hydrophobic substance is one that does not have an affinity for water

Concept 1.1.6: Dissociation of water molecules leads to acidic and basic conditions that affect living organisms

- A hydrogen atom in a hydrogen bond between two water molecules can shift from one to the other:
  - The hydrogen atom leaves its electron behind and is transferred as a proton, or hydrogen ion (H^+)
  - The molecule with the extra proton is now a hydronium ion (H_3O^+)
  - The molecule that lost the proton is now a hydroxide ion (OH^-)



The pH Scale



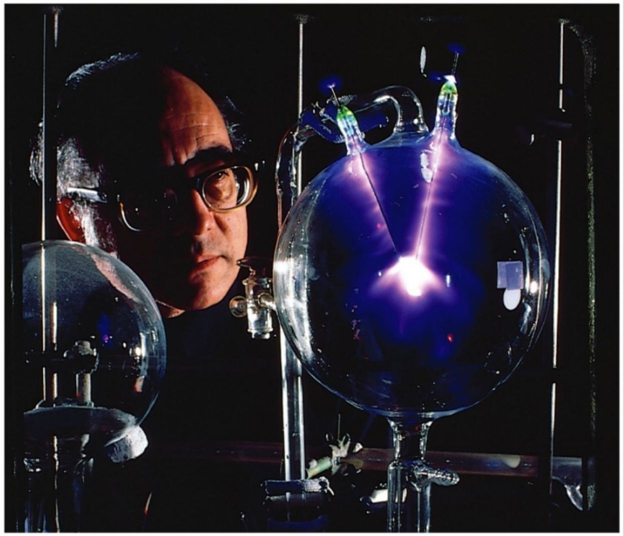
- The pH of a solution is determined by the relative concentration of hydrogen ions
- Acidic solutions have pH values less than 7
- Basic solutions have pH values greater than 7
- Most biological fluids have pH values in the range of 6 to 8
- Buffers are substances that minimize changes in concentrations of H^+ and OH^- in a solution

Carbon—The Backbone of Biological Molecules

- Although cells are 70–95% water, the rest consists mostly of carbon-based compounds
- Carbon is unparalleled in its ability to form large, complex, and diverse molecules
- Proteins, DNA, carbohydrates, and other molecules that distinguish living matter are all composed of carbon compounds

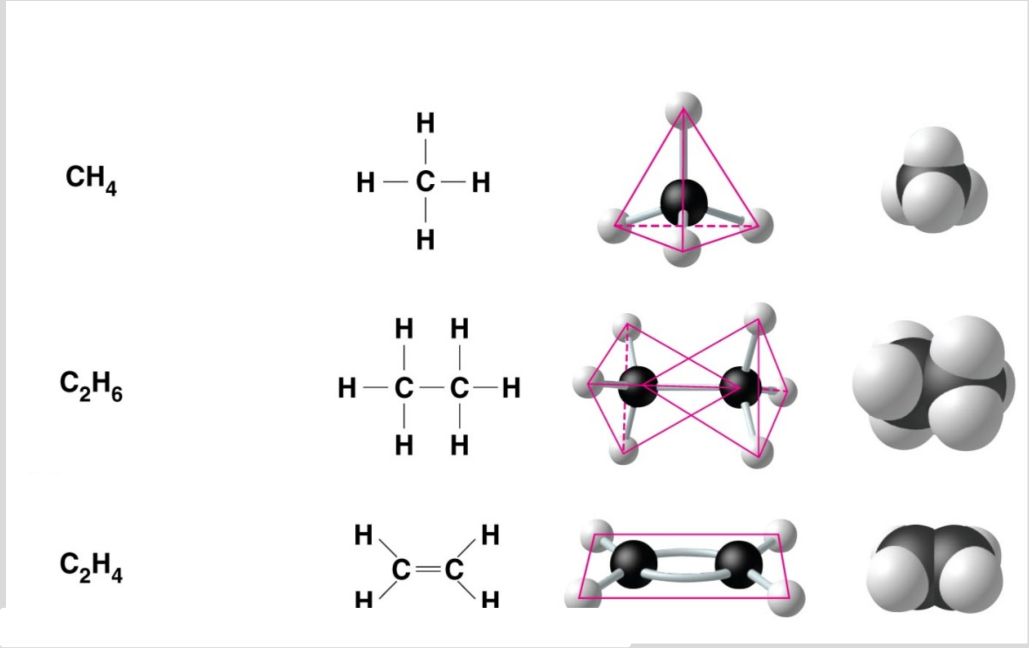
Concept 1.1.7: Organic chemistry is the study of carbon compounds

- Organic compounds range from simple molecules to colossal ones
- Most organic compounds contain hydrogen atoms in addition to carbon atoms
- Vitalism, the idea that organic compounds arise only in organisms, was disproved when chemists synthesized the compounds



Concept 1.1.8: Carbon atoms can form diverse molecules by bonding to four other atoms

- With four valence electrons, carbon can form four covalent bonds with a variety of atoms
- In molecules with multiple carbons, each carbon bonded to four other atoms has a tetrahedral shape
- However, when two carbon atoms are joined by a double bond, the molecule has a flat shape



Methane

Ethane

Ethene (ethylene)

Concept 1.1.9: Functional groups are the parts of molecules involved in chemical reactions

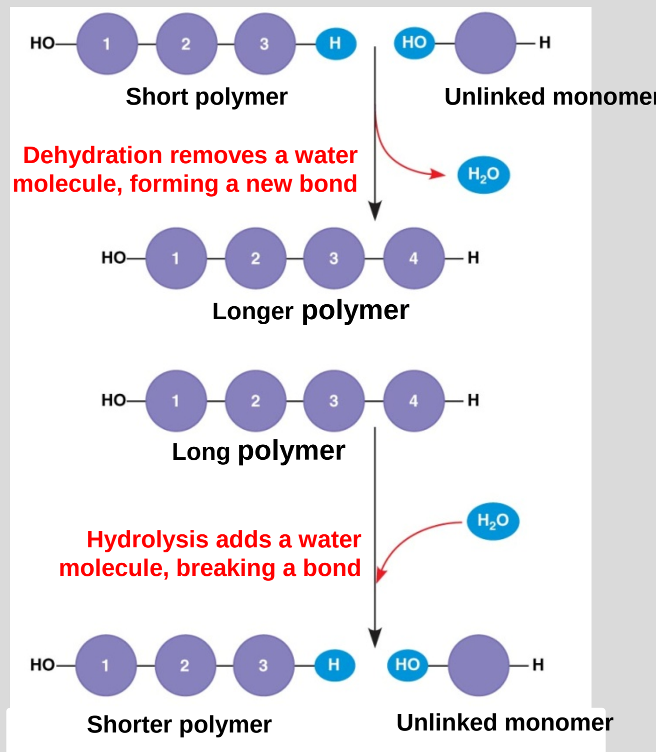
- Distinctive properties of organic molecules depend not only on the carbon skeleton but also on the molecular components attached to it. The six functional groups that are most important in the chemistry of life:
  - Hydroxyl group
  - Carbonyl group
  - Carboxyl group
  - Amino group
  - Sulfhydryl group
  - Phosphate group

The Molecules of Life

- Within cells, small organic molecules are joined together to form larger molecules
- Macromolecules are large molecules composed of thousands of covalently connected atoms
- A polymer is a long molecule consisting of many similar building blocks called monomers
- Three of the four classes of life's organic molecules are polymers:
  - Carbohydrates
  - Proteins
  - Nucleic acids

The Synthesis and Breakdown of Polymers

- Monomers form larger molecules by condensation reactions called dehydration reactions
- Polymers are disassembled to monomers by hydrolysis, a reaction that is essentially the reverse of the dehydration reaction

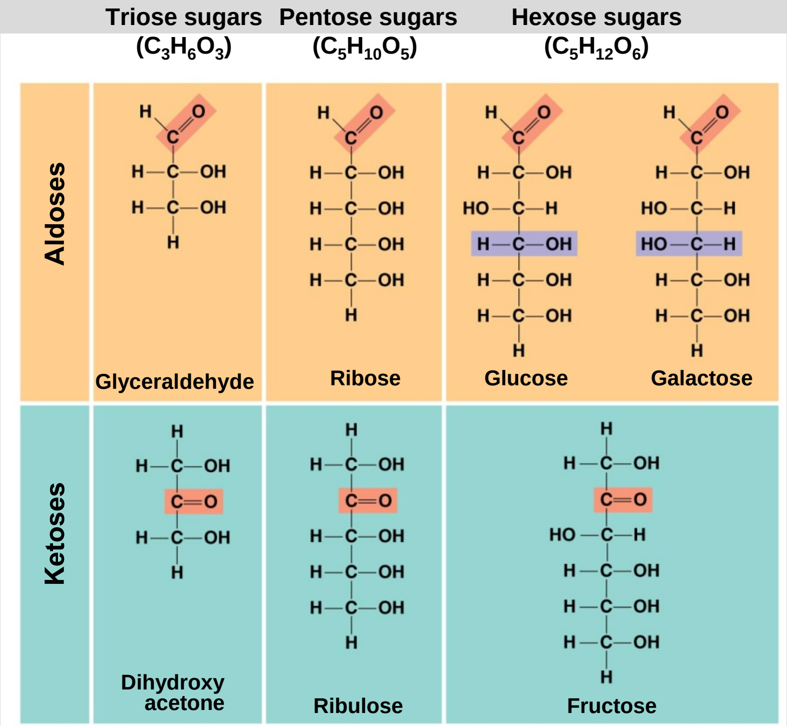


Animation: Polymers

Concept 1.1.10: Carbohydrates serve as fuel and building material

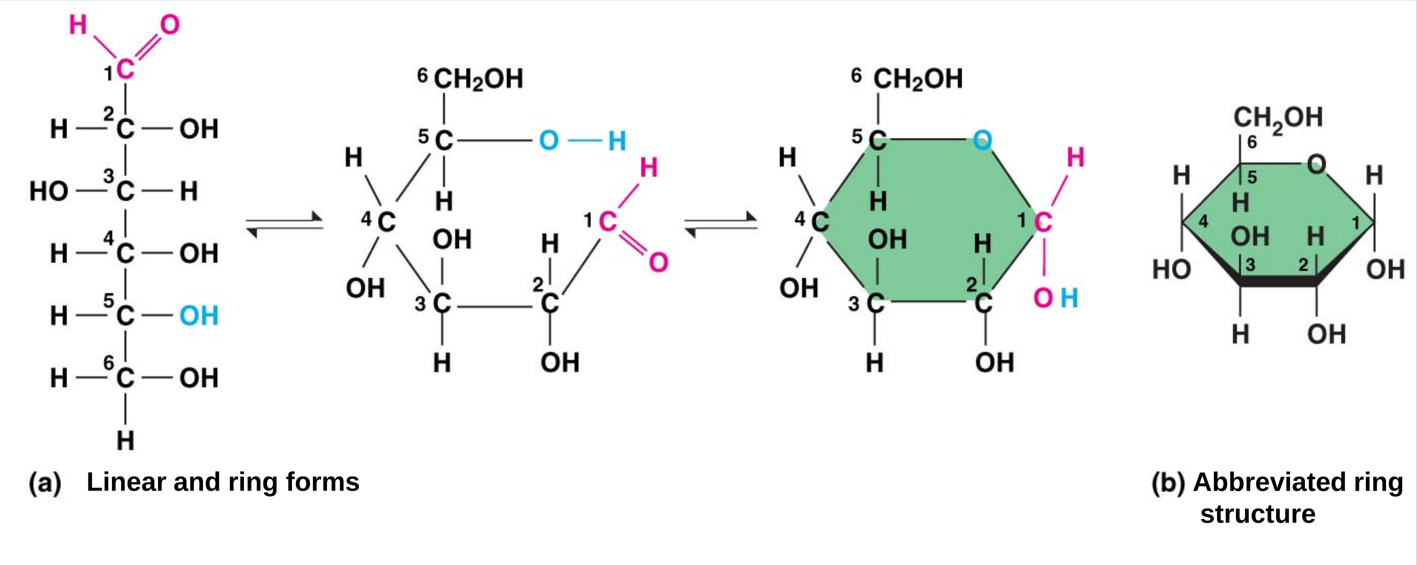
- Carbohydrates include sugars and the polymers of sugars
- The simplest carbohydrates are monosaccharides, or single sugars

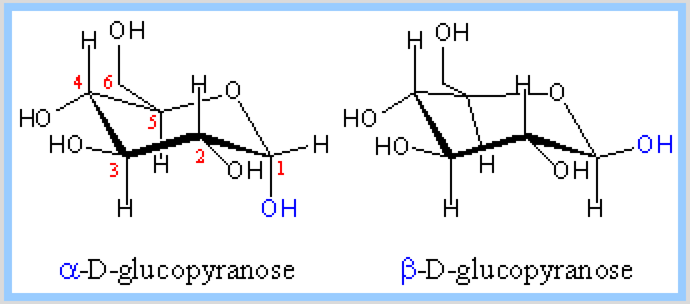
- Monosaccharides have molecular formulas that are usually multiples of CH_2O
- Monosaccharides are classified by location of the carbonyl group and by number of carbons in the carbon skeleton



Sugars

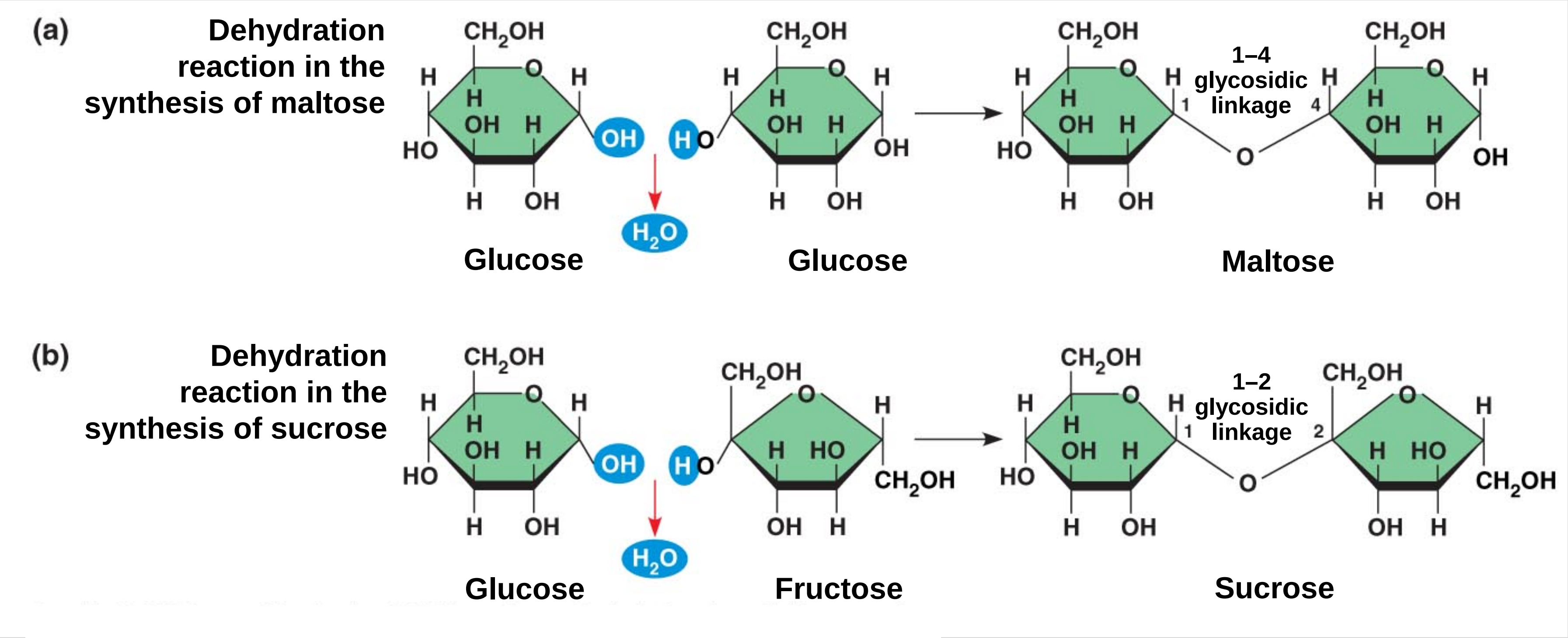
- Monosaccharides serve as a major fuel for cells and as raw material for building molecules
- Though often drawn as a linear skeleton, in aqueous solutions they form rings





Sugars

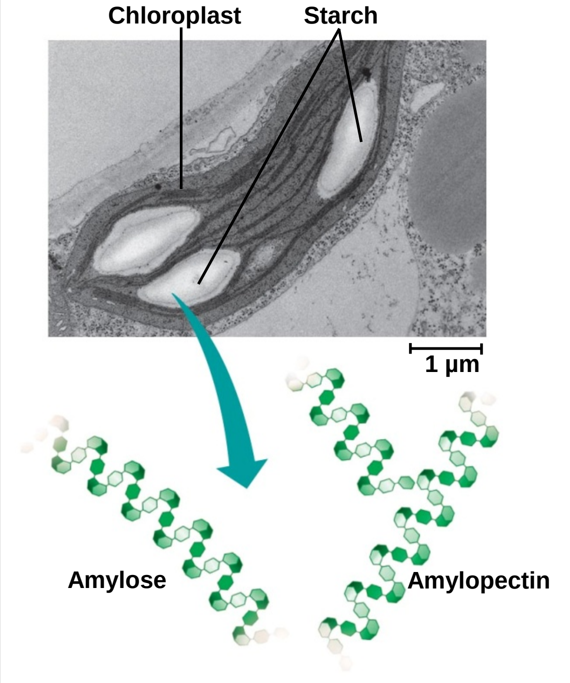
- A disaccharide is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a glycosidic linkage



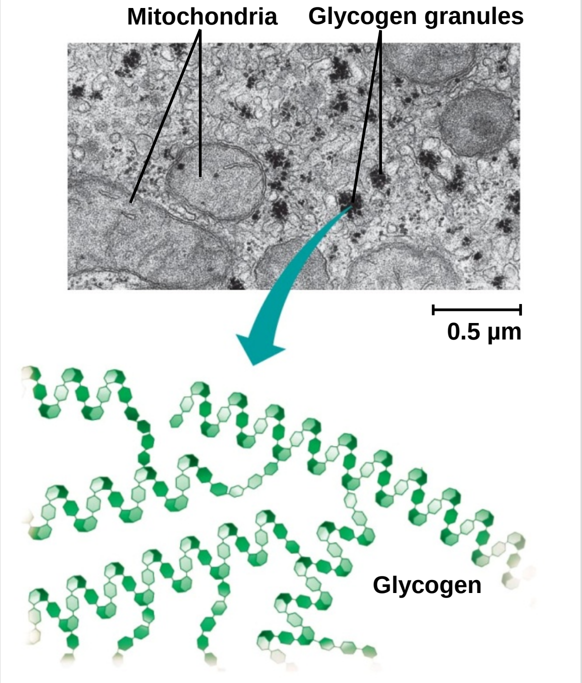
Animation: Disaccharides

Polysaccharides

- Polysaccharides, the polymers of sugars, have storage and structural roles
- The structure and function of a polysaccharide are determined by its sugar monomers and the positions of glycosidic linkages



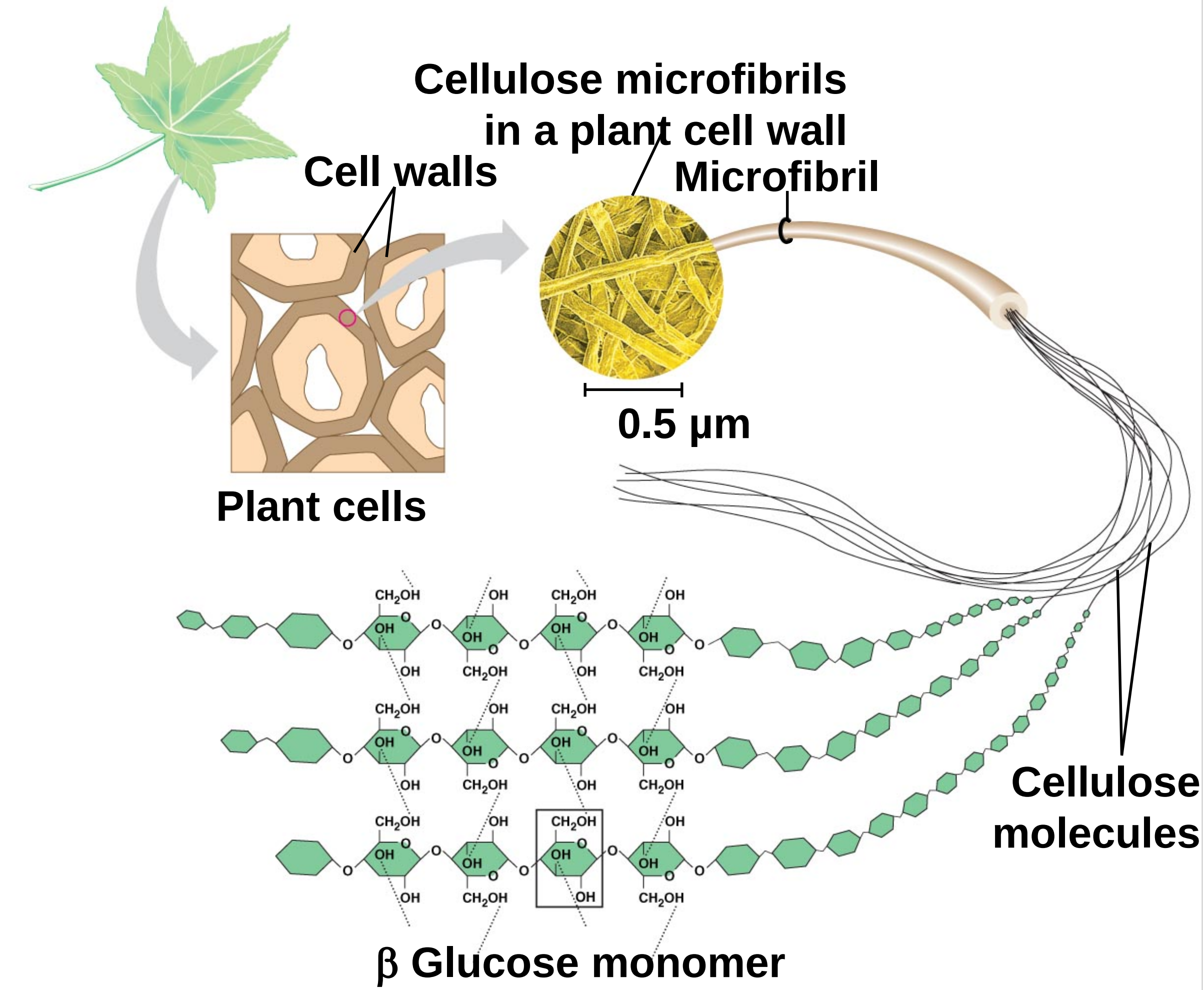
Starch: a plant polysaccharide



Glycogen: an animal polysaccharide

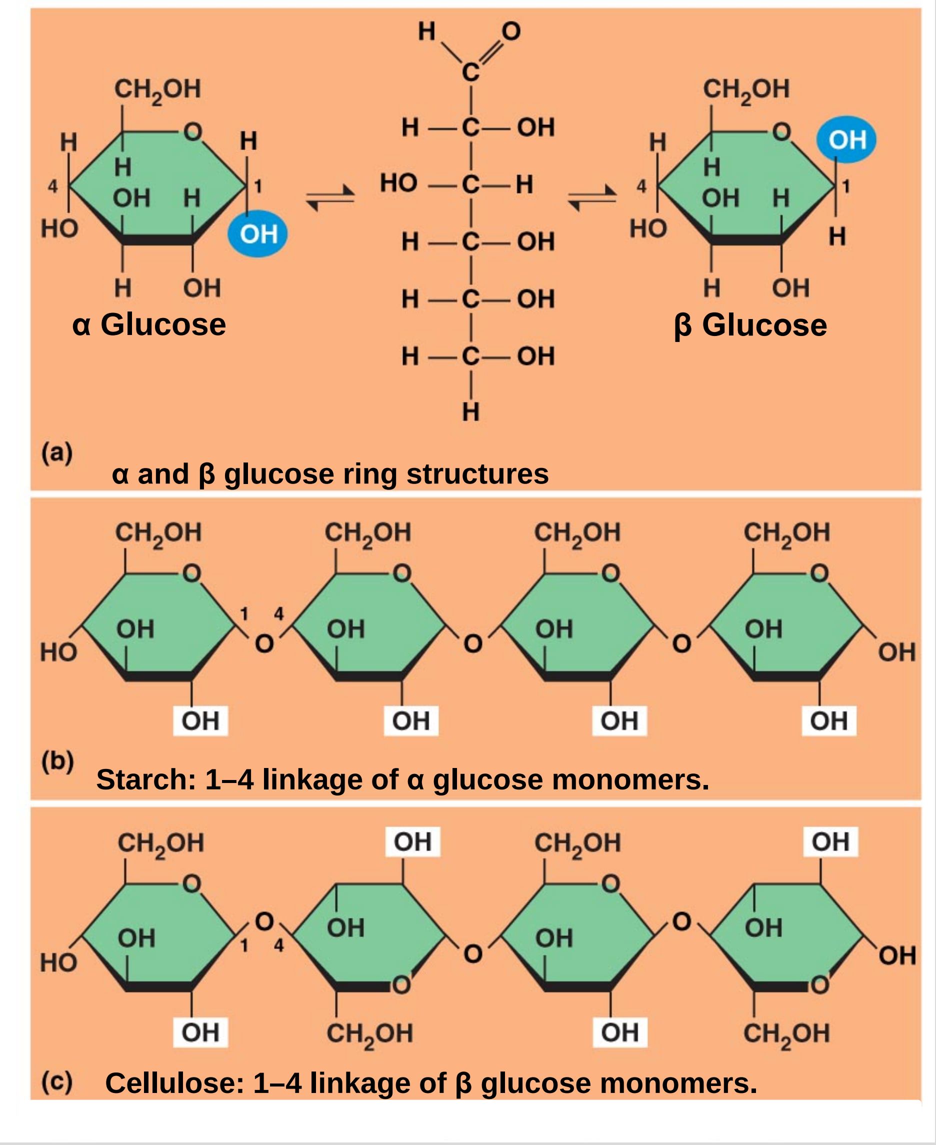
Structural Polysaccharides

- Cellulose is a major component of the tough wall of plant cells



Structural Polysaccharides

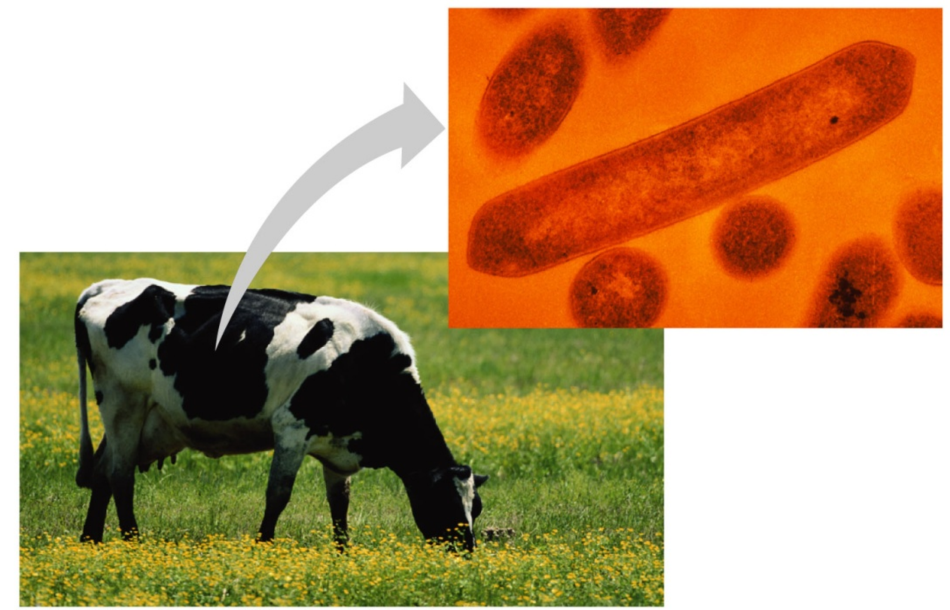
- Like starch, cellulose is a polymer of glucose, but the glycosidic linkages differ
- The difference is based on two ring forms for glucose: alpha (α) and beta (β)
- Polymers with alpha glucose are helical
- Polymers with beta glucose are straight



Animation: Polysaccharides

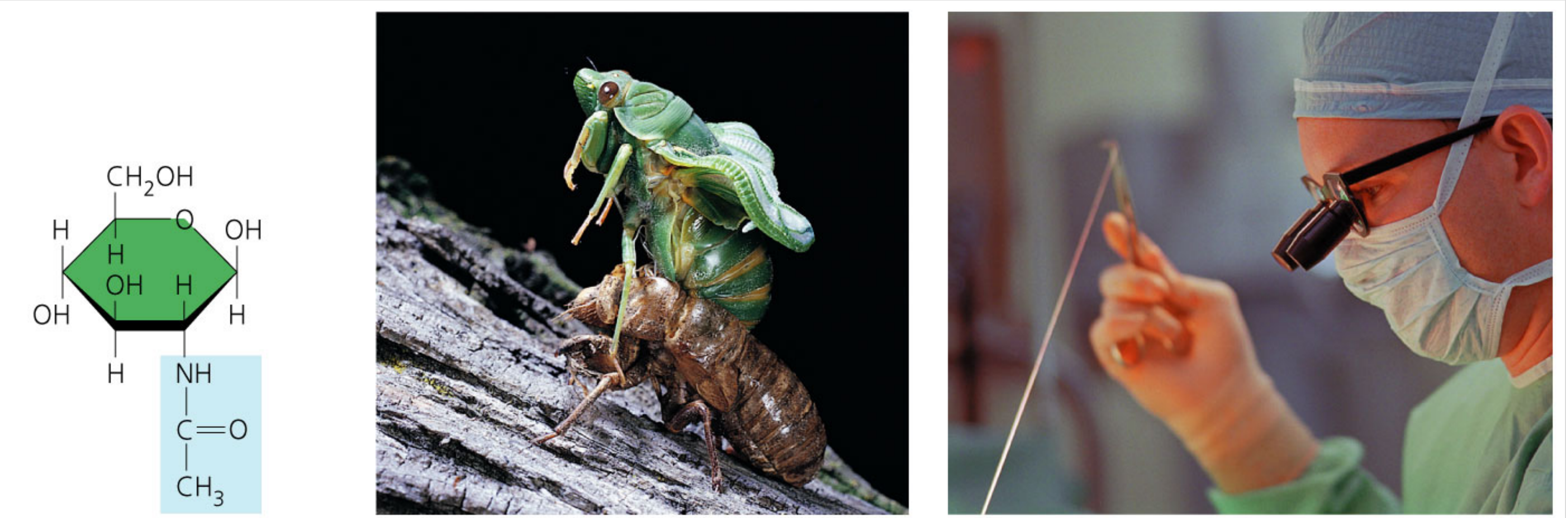
Structural Polysaccharides

- Enzymes that digest starch by hydrolyzing alpha linkages can’t hydrolyze beta linkages in cellulose. Cellulose in human food passes through the digestive tract as insoluble fiber
- Some microbes use enzymes to digest cellulose. Many herbivores, from cows to termites, have symbiotic relationships with these microbes



Structural Polysaccharides

- Chitin, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi
- Chitin can be used as surgical thread



(a) The structure of chitin.

(b) Chitin forms the exoskeleton of arthropods. This cicada is molting, shedding its old exoskeleton and emerging in adult form.

(c) Chitin is used to make a strong and flexible surgical thread that decomposes after the wound or incision heals.